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THE NATURE OF THE PERCEPTION OF EFFORT AT SEA LEVEL AND HIGH AL--ETC(U)
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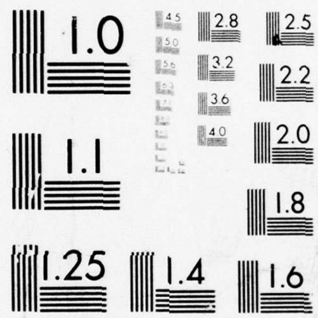

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The Nature of the Perception of Effort at Sea Level and High Altitude

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Running Head: RPE at High Altitude

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This study compared the

Abstract

Rating of Perceived Exertion

The purpose of this study was to compare (RPE) and selected physiological measures, during both short term and prolonged work of equal relative intensities (i.e., % $\dot{V}O_2$ max), at 4300 m to those at sea level. Ss (n = 20) performed bicycle work at supramaximal intensities, for six minutes each at 60, 80 and 95% $\dot{V}O_2$ max and to exhaustion at 85% $\dot{V}O_2$ max. At 4300 m, $\dot{V}O_2$ max was reduced 19%, while $\dot{V}_E$ max and R max increased 17 and 8%, respectively; HR max and RPE max was unchanged. For any given relative work intensity, $\dot{V}O_2$ and absolute work intensity (kpm·min^{-1}) were of course reduced, while $\dot{V}_E$ was about 12% and R about 7% greater at 4300 m; again HR was unchanged. At 4300 m, RPE at the lower intensities and early during prolonged work were significantly less than at sea level. These differences were reduced and finally eliminated as work intensity increased toward maximal or as prolonged work continued to exhaustion. Endurance time to exhaustion at 4300 m was not different from that at sea level. To account for the perceptual differences between work at 4300 m and sea level we proposed that RPE was a positively acclerating power function of central influences (tachycardia, tachypnea, dyspnea), and either a linear or positively decelerating power function of local influences (muscular strain).

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Key Words: perceived exertion, RPE, relative work intensity, hypoxia, high altitude, central factors, local factors

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Introduction

As in the case of many physiological variables, the rating of perceived exertion (RPE), as described by Borg (3), was observed to be a linear function of relative work intensity (i.e. % maximal aerobic capacity or $\dot{V}O_2$ max) across many different states or conditions (5,17). Disturbances in the functional relationship between RPE and relative work intensity have been suggested for situations in which the tension developed by local musculature differed at equal metabolic rates and assumedly equal relative intensities (11,15,19). If work performed at high altitude is equated on a relative basis to that at sea level a unique situation arises in which some parameters, such as minute ventilation and respiratory exchange rates are greater at high altitude than at sea level; others, such as cardiac output, heart rate, stroke volume and blood lactate concentration are not different between the two conditions; while absolute work intensity (thus also the tension developed by local musculature) is less at high altitude than at sea level. This raises the question as to what are the effects of high altitude on the functional relationship between RPE and relative work intensity. The general purpose of this study was to compare perceptual responses during both short term and prolonged work of equal relative intensities at high altitude (4300 m) to those at sea level. Specifically, we compared RPE obtained at approximately 60, 80 and 95% $\dot{V}O_2$ max and RPE obtained at five minute intervals during work to exhaustion at 85% $\dot{V}O_2$ max.

Methods

Twenty healthy, male volunteers served as subjects for this study. Their mean age was 19.8 yrs, S.E. ± 0.2, mean height was 180.0 cm, S.E. ± 1.2, mean weight was 73.5 kg, S.E. ± 2.0. All subjects were medically screened, including medical history, physical examination, chest x-ray, urinalysis, CBC, and hemoglobin electrophoresis. Potential subjects were excluded from the study if they were born at an altitude in excess of 1000 m, had resided over one month at an altitude over 1000 m within three years, or had sojourned to an altitude over 3000 m within three months prior to this study. Further basis for exclusion included evidence of any hemoglobinopathy or other illness which would contraindicate sojourn at high altitude. In the presence of a physician, each volunteer was fully informed of all procedures to be used and of all experimental conditions, including expected effects thereof, and signed a statement of informed consent.

Initially, at sea level, subjects were familiarized with all testing procedures, including riding the bicycle ergometer at both submaximal and maximal work intensities for both short and prolonged periods of time. During the familiarization period measurements of $\dot{V}O_2$ were obtained for estimation of work intensities corresponding to $\dot{V}O_2$ max and various percentages thereof. Following familiarization, subjects repeated a series of tests on three separate occasions at sea level and on one occasion at high altitude. Each testing repetition was conducted over two consecutive

days with three days rest in between each repetition. Testing on the first day consisted of six minutes of work at submaximal intensities corresponding to approximately 60, 80, and 95% $\dot{V}O_2$ max and four to five minutes of work at two supramaximal work intensities for the determination of $\dot{V}O_2$ max. On the second day subjects performed work to exhaustion at an intensity approximating 85% $\dot{V}O_2$ max. Sea level studies were conducted over a three week period. On the third day of rest, following the third testing repetition at sea level, subjects were transported by pressurized aircraft and automobile to Pike's Peak, Colorado for study at 4300 m. First day tests were begun on the morning following the day of arrival at 4300 m and were completed for all subjects within 24 hours following the time of arrival. Second day tests were begun the next morning and completed for all subjects within 48 hours following the time of arrival at 4300 m. All exercise tests were performed on an electrically braked bicycle ergometer; subjects were attired in loose fitting shorts, shocks and tennis shoes. Paper electrodes were affixed to the subject's upper torso for the monitoring of EKG. For the short exercise bouts, at both submaximal and maximal intensities, timed collections of expired air were obtained during the final minute for determination of ventilatory and metabolic parameters; while heart rate (HR) and RPE were ascertained during the final ten seconds. During prolonged work to exhaustion, HR and RPE were ascertained at five minute intervals and at exhaustion, while expired air was collected during the sixth minute. Although the bicycle ergometers used in this study adjust pedal resistance to maintain a fixed work intensity (in kpm·min^{-1})

regardless of pedal frequency, all work was performed at a frequency of 60 rpm. In the case of prolonged work, exhaustion was defined as the point at which the subject was unable to maintain pedal frequency above 50 rpm. The criterion for $\dot{V}O_2$ max was a plateauing of $\dot{V}O_2$ concommitant with an increase in work intensity.

Heart rate was measured from standard EKG tracings as EKG was monitored continuously throughout all tests, RPE was ascertained from the Borg scale (3). Expired air was collected via a Collin's Triple-J valve into vinyl Douglas bags and analyzed for fraction of O_2 with a Beckman E2 paramagnetic oxygen analyzer and for fraction of CO_2 with a Beckman LB2 infrared CO_2 analyzer. Expired air volume was ascertained by withdrawing the contents of each Douglas bag into a calibrated tissot spirometer. Minute ventilation ($\dot{V}_E$) corrected to BTPS, $\dot{V}O_2$ corrected to STPD, and respiratory exchange ratio (R) were calculated.

Results

At sea level both $\dot{V}O_2$ max and endurance time to exhaustion increased from the first to the second repetition; while there were no differences between the second and third repetitions. For comparison purposes we have included data from both the second (SL_2) and third (SL_3) sea level repetitions as well as that from 4300 m (HA). As indicated in Table 1 there were no differences in $\dot{V}O_2$ max or the other maximal measures between SL_2 and SL_3. Upon sojourn to 4300 m, $\dot{V}O_2$ max was reduced 19%, while $\dot{V}_E$ max and R max increased 17 and 8%, respectively; HR max was unchanged. Figure 1 depicts RPE and the various physiological measures as functions of relative work intensity. Again there were no differences between SL_2 and SL_3 for any of the measures. Absolute work intensities (mean ± S.E.)

corresponding to 60, 80 and 95% $\dot{V}O_2$ max were 710 ± 30, 1017 ± 30 and 1269 ± 32 $kpm \cdot min^{-1}$, respectively, at SL, and 495 ± 24, 782 ± 26 and 1060 ± 28 $kpm \cdot min^{-1}$, respectively at HA. $\dot{V}O_2$ was reduced at HA to accommodate the reduction in $\dot{V}O_2$ max and achieve a given relative work intensity. For any given relative work intensity, $\dot{V}_E$ was about 12% and R about 7% greater at HA than at SL, while there were no differences in HR between the two conditions. At 60% $\dot{V}O_2$ max, RPE was about 1.0 less at HA than at SL. As relative work intensity increased, differences in RPE between HA and SL diminished so that at 80% $\dot{V}O_2$ max RPE at HA was only about 0.5 less than at SL, while at 95% $\dot{V}O_2$ max there was no difference in RPE between the two conditions.

As indicated in Table 2 and Figure 2 there were also no differences between SL_2 and SL_3 for any of the measures obtained during the endurance rides to exhaustion at 85% $\dot{V}O_2$ max. Endurance time to exhaustion (ET) at HA was not different from that at SL. Absolute work intensities (mean ± S.E.) corresponding to 85% $\dot{V}O_2$ max were 1077 ± 28 and 866 ± 22 $kpm \cdot min^{-1}$ at SL and HA, respectively. Again, $\dot{V}O_2$ was reduced at HA to accommodate the reduction in $\dot{V}O_2$ max and achieve 85% $\dot{V}O_2$ max. At 85% $\dot{V}O_2$ max, $\dot{V}_E$ was 23% and R was 7% greater at HA than at SL. At both HA and SL, HR increased throughout the endurance rides, achieving near maximal levels at exhaustion; HR was slightly less at HA than at SL. At both HA and SL, RPE increased linearly throughout the endurance rides, achieving maximal levels at exhaustion. At 25% ET, RPE was 0.7 less at HA than at SL. As time progressed, these differences between HA and SL diminished so that at 75% ET there was no difference in RPE between the two conditions, while at exhaustion RPE at HA was slightly higher than that at SL.

Discussion

For a given set of working conditions, the degree of effort perceived by a given subject is a function of the absolute intensity of the work performed or the metabolic rate required to accomplish said work (3). When working conditions were varied, as in the cases of cycling vs treadmill work (18) or arm vs leg work (7), or when the functional state of the subject was changed, as in the case of physical training (4,5), the perception of effort at a given absolute work intensity or metabolic rate was different. However, when equated on a relative basis (i.e., as % $\dot{V}O_2$ max), the differences in RPE among individual subjects, work modes and training state was greatly reduced and RPE was a strict function of relative work intensity (5,17). Disturbance in the functional relationship between RPE and relative work intensity have been suggested by studies in which pedalling frequency during bicycle work was varied while work intensity and metabolic rate were held constant (15,19). In these studies the effort required to pedal at low frequencies (<40 rpm) was perceived to be greater than that at higher frequencies (>60 rpm). The increased mechanical resistance required to equate work intensity at low to that at higher frequencies prompted these authors to suggest the influence of increased local muscular strain as responsible for the higher ratings of perceived exertion observed at low frequencies. The existance of both local and central factors, as influences on the perception of effort, had previously been suggested (5). However, local factors (e.g., muscular strain) were thought to be the dominent influence for work with small muscle groups, while central factors (e.g., tachycardia and tachypnea) were thought to be the dominent influence for work with large muscle groups. These other

studies (15,19) now suggest a significant influence of local factors in the perception of effort for work involving the large muscle groups.

Our data shows that when work is equated on a relative basis, as expected, V_E at 4300 m was greater and HR was equal to that at sea level. This suggests that the influence of these central factors on the perception of effort at a given relative intensity should be the same or greater at high altitude than at sea level. Moreover because pedal resistance was necessarily reduced to achieve a given relative intensity, we can assume that muscular strain at 4300 m was less than at sea level. This suggests that the influence of local factors on the perception of effort at a given relative intensity should be less at high altitude than at sea level. With these facts in mind, the question remained as to whether at high altitude the perception of effort for work of equal relative intensity would differ from that at sea level. An increase in RPE for work of equal absolute intensity performed under hypoxic conditions (8) or at high altitude (6) over that at sea level has been previously reported. Kinsman and Weiser (11), in their review of perceptual responses during work, report some unpublished observations by Weiser et. al. who studied RPE responses to work of equal relative intensities (30, 60 and 100% $\dot{V}O_2$ max) at 1600 m and at 4300 m. They observed RPE to be the same at both altitudes.

For work within the range of 60 to 95% $\dot{V}O_2$ max, our results indicate that at the low end of the range RPE at high altitude was significantly less than at sea level, while at the high end of the range there was no difference for RPE between the two conditions. There was also no difference between high altitude and sea level for RPE obtained during maximal work,

although work times were not constant nor were supramaximal work intensities equated among the subjects as with submaximal work. These results suggest that local factors exerted greater influence on the perception of effort at work intensities which did not greatly stress ventilation and circulation, while central factors exerted a greater influence on the perception of effort at work intensities which resulted in tachycardia and tachypnea of sufficient magnitude to be perceived as extremely stressful by the subjects. As indicated by studies in which the functional relationships among HR, RPE and work intensity (2) have been experimentally altered (5,10,12,14), there is a question as to whether perceived tachycardia plays a role in the perception of effort. For purposes of this discussion we will assume perceived tachycardia to be a central factor influencing perception of effort and discuss our data in light of this assumption.

Our results from the endurance runs at 85% $\dot{V}O_2$ max tend to support the aforestated position. Initially RPE at high altitude was significantly less than at sea level; as work continued this difference between the two altitudes disappeared. Heart rate, which initially was less than 170 bpm, achieved near maximal levels at the same time as RPE at high altitude achieved equality with that at sea level. While we did not serially measure $\dot{V}_E$ in this study, we previously observed that during work to exhaustion at 80% $\dot{V}O_2$ max, $\dot{V}_E$ increased at a rate of nearly 2.0 L/min·min^{-1} (9). Assuming that in this study, $\dot{V}_E$ increased at at least this rate, at exhaustion we could expect $\dot{V}_E$ to have been about 95% $\dot{V}_E$ max. Further, assuming tachycardia

and tachypnea are perceived, and influence perception of effort, we would expect this influence to be greater as maximal levels were approached.

We are not suggesting that subjects were completely unaware of central factors influencing perception of effort at lower work intensities or early during prolonged work. Indeed, Noble et. al. (13) observed differences in ventilation during prolonged work at 48 through 68% $\dot{V}O_2$ max accounted for most of the variance in RPE among subjects. We are suggesting that, within the specific framework of our study (i.e., 60-95% $\dot{V}O_2$ max, limited measurements) we can account for the observed perceptual differences between high altitude and sea level if we consider the functional relationship between perception of effort and central influences to be different from that between perception of effort and local influences. While both influences are active at all work intensities, we are proposing that perception of effort is a positively accelerating power function of central influences and either a linear or positively decelerating power function of local influences. The intercepts and exponents of these functions cannot be described with existing data, but the two curves do intercept at some point in the high range of relative intensity. It is obvious that these proposed functional differences fit our data very well. Considering central factors, there is support of our proposed functional relationship with perception. Respiration is probably the most significant perceptual influence (13). Some sensations contributing to this influence are probably located in the musculature of the chest. It is fitting that respiration associated with work at higher intensities involves active expiration and therefore more of the muscles of the chest. Another source

of sensations contributing to respiratory influences is the sense of exertional dyspnea. These sensations result from chemoreceptor stimulations caused by an increase in arterial hydrogen ions (H^+). The pattern of response of arterial H^+ and lactate production (the major source of H^+) is also a positively accelerated power function of increasing work intensity. Moreover, Bakers and Tenney (1) observed that the perception of magnitude of ventilation was also a positively accelerated power function of actual $\dot{V}_E$.

Considering local factors (16)*, there is also support of the proposal that sensory input to perception of effort represents a positively decelerating power function. Recruitment of the number of motor units and thus the number of muscle fibers involved in the development of tension reaches a maximal level well in advance of maximal tension development. Assuming the precontraction stretch of the sarcomere and its length during contraction are optimal for the development of maximal tension, increases in tension are then dependent on increases in the frequency of activation of individual motor units. As the frequency of activation of motor units increases, there is summation to form tetanus, which results in an increase in the ratio of developed tension to active motor units. Thus at work intensities requiring less tension, more motor units (and thus more musculature) per unit time are required to effect a given unit of tension development.

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*The following discussion is based on information provided in chapters 4 through 7 of the noted reference and as such are considered accepted truisms; therefore, we will not reference specific studies.

Moreover, the rate of receptor discharge from the most logical source of contributory sensations to local influences, i.e., stretch and tension receptors such as muscle spindles and Golgi tendon bodies, is a positively decelerating power function of stretch, tension and velocity of stretch (proportional to rate of activation).

In summary, we have shown the functional relationship between perception of effort and relative work intensity at high altitude to be different from that at sea level. Specifically, at high altitude, RPE at a moderate work intensity and early during prolonged work were significantly less than at sea level. These differences were reduced and finally eliminated as work intensity increased toward maximal levels or as prolonged work continued to exhaustion. To account for the perceptual differences between high altitude and sea level we proposed that the functional relationship between perception of effort and central influences (tachycardia, tachypnea, dyspnea) is different from the functional relationship between perception of effort and local influences (muscular strain). Specifically, we proposed that perception of effort was a positively accelerating power function of central influences, and either a linear or positively decelerating power function of local influences.

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Table 1: Mean ± S.E. (n=20) $\dot{V}O_2$ Max and Other Maximal Parameters for SL_2, SL_3 and HA Maximal Rides

		SL_2	SL_3	HA
$\dot{V}O_2$	$(L \cdot min^{-1})$	3.55 ± 0.05	3.53 ± 0.05	2.85* ± 0.04
$\dot{V}O_2$	$(ml \cdot kg^{-1} \cdot min^{-1})$	48.8 ± 1.2	48.4 ± 1.1	39.1* ± 0.9
$\dot{V}_E$ BTPS	$(L \cdot min^{-1})$	137 ± 4	140 ± 4	162 ± 4*
R	—	1.15 ± 0.01	1.16 ± 0.01	1.25 ± 0.01*
HR	bpm	185 ± 2	183 ± 2	180 ± 2
RPE	—	17.9 ± 0.4	17.5 ± 0.04	17.7 ± 0.3

*HA significantly different ($p<0.01$) from mean of SL_2 and SL_3 by paired t-test comparison.

Table 2: Mean ± S.E. (n=20) Endurance Times, Metabolic and Ventilatory Parameters for SL_2, SL_3 and HA Endurance Rides at 85% $\dot{V}O_2$ Max

		SL_2	SL_3	HA
ET	(min)	23.2 ± 3.0	24.4 ± 2.8	22.4 ± 2.6
$\dot{V}O_2$	($L \cdot min^{-1}$)	2.97 ± 0.07	3.01 ± 0.06	2.41 ± 0.05*
$\dot{V}_E$ BTPS	($L \cdot min^{-1}$)	94 ± 4	96 ± 4	117 ± 5*
R	—	0.93 ± 0.01	0.95 ± 0.01	1.01 ± 0.02*

*HA significantly different ($p<0.01$) from mean of SL_2 and SL_3 by paired t-test comparison.

Figure Legend

Figure 1. Mean ± S.E. (n=20) RPE and physiological measures as functions of relative work intensity for SL_2 (●—●), SL_3 (◆—◆) and HA (○—○).

Figure 2. Mean ± S.E. (n=20) RPE and HR as functions of % endurance time for SL_2 (●—●), SL_3 (◆—◆) and HA (○—○).

The views of the author do not purport to reflect the positions of the Department of the Army or the Department of Defense.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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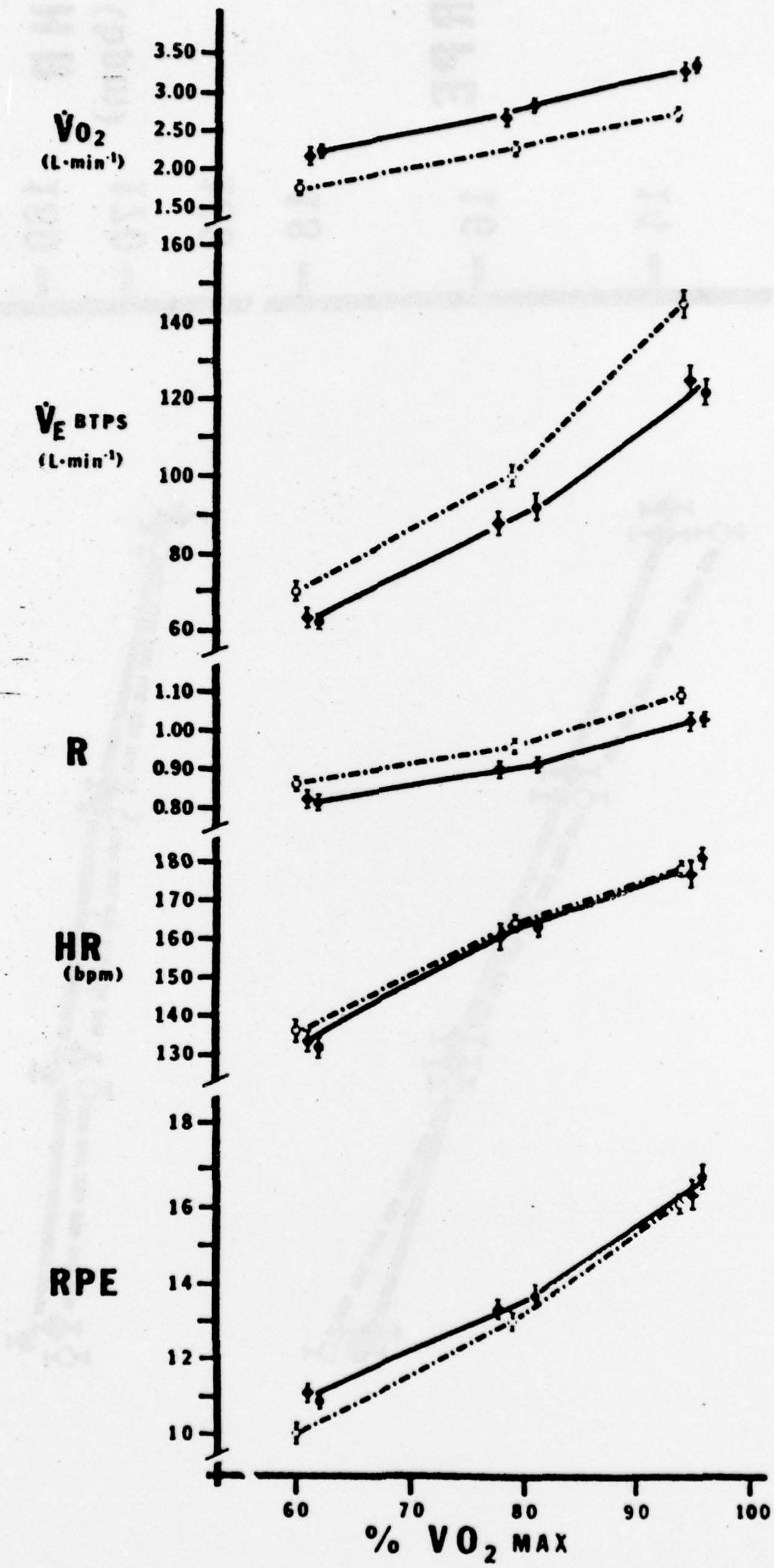
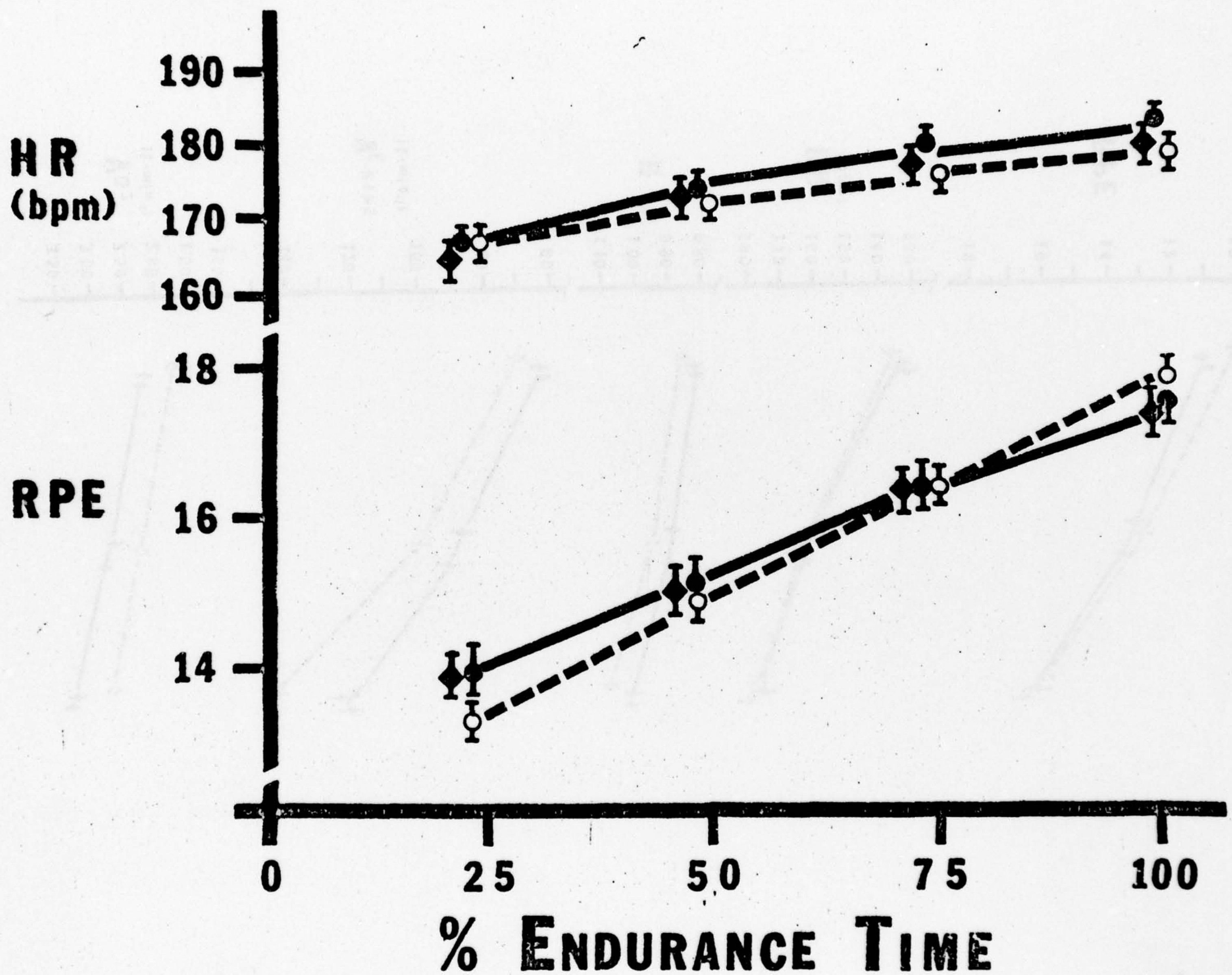
Fig 1



$\dot{V}O_2$ (L·min⁻¹)
3.50
3.00
2.50
2.00
1.50
$\dot{V}_E$ BTPS (L·min⁻¹)
160
140
120
100
80
60
R
1.10
1.00
0.90
0.80
HR (bpm)
180
170
160
150
140
130
RPE
18
16
14
12
10
60
70
80
90
100
% VO2 MAX

Fig 2



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
The purpose of this study was to compare RPE, and selected physiological measures,, during both short term and prolonged work of equal relative intensities (i.e., % $\dot{V}O_2$ max), at 4300 m to those at sea level. Ss (n=20) performed bicycle work at supramaximal intensities, for six minutes each at 60, 80 and 95% $\dot{V}O_2$ max and to exhaustion at 85% $\dot{V}O_2$ max. At 4300 m, $\dot{V}O_2$ max was reduced 19%, while $\dot{V}_E$ max and R max increased 17 and 8%, respectively; HR max and RPE max was unchanged. For any given relative work intensity, $\dot{V}O_2$ and absolute work

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intensity ($kpm \cdot min^{-1}$) were of course reduced, while $\dot{V}_E$ was about 12% and R about 7% greater at 4300 m; again HR was unchanged. At 4300 m, RPE at the lower intensities and early during prolonged work were significantly less than at sea level. These differences were reduced and finally eliminated as work intensity increased toward maximal or as prolonged work continued to exhaustion. Endurance time to exhaustion at 4300 m was not different from that at sea level. To account for the perceptual differences between work at 4300 m and sea level we proposed that RPE was a positively accelerating power function of central influences (tachycardia, tachypnea, dyspnea), and either a linear or positively decelerating power function of local influences (muscular strain).

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